Study of a method-time measurement system in an electronics assembly line

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“Never (…) was so much owed by so many to so few”- Winston Churchill

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With the globalization of markets and an increasingly competitive environment of the industrial electronics sector, there is a need to the optimize processes, the development of new solutions and standards.

Bosch, like the rest of the industrial sector, aims for continuous improvement, and the Bosch Ovar Plant has as a target, until the end of the year, the implementation of a predetermined method-time system. This system allows an accurate time prediction of the work cells processes, when planning production and the optimization of work cells following the principals of motion economy. Even though the link between the use of a method-time measurement system and company performance is hard to measure, the capacity to "predict" time of products can result in economical and time savings.

During the project, various work cells in the Bosch Ovar plant were studied: its methods and processes (from regular assemblies to welding) and their corresponding time; and both test if the use of a method-time system was possible, and in that case, which of the systems would be more appropriate (MTM.1; MTM-UAS; MTM-MEK).

It was possible to conclude that the use of MTM-UAS system was preferred over the use of MTM-1, based on the simplicity, accuracy of times in batch production and the processes present at Bosch Ovar Plant. However, in some work cells, the use of a MTM system was not possible, mainly due to processes complexity or mechanization of the movements within the work cells.

Estudo de um Sistema de medida de métodos e tempos numa linha de assemblagem de produtos eletrónicos

A globalização dos mercados económicos bem como a crescente competitividade no sector industrial de eletrónica conduz à otimização de processos, ao desenvolvimento de novas soluções e *standards.*

A Bosch, à semelhança de todo o setor industrial, visa melhoria continua. Na fábrica de Bosch Ovar está estabelecido como objetivo a implementação, até o final do ano, de sistemas de medição de métodos e tempos. Estes sistemas permitem a previsão com precisão do trabalho nas células de produção antes das mesmas estarem ativas bem como a otimização de métodos tendo por base os princípios da *"motion economy".* Não obstante a dificuldade de estabelecer relações quantificáveis entre os sistemas de medição de métodos e tempos e a eficiência da produção, é válida a correlação entre o uso destes sistemas e a minimização de perdas a nível de tempos e económicos.

No âmbito deste projeto foram estudadas células de produção, designadamente: os seus processos e métodos de trabalho (desde a montagem até processos de solda) e os tempos da sua realização; averiguar se é possível aplicar sistemas de medição de métodos e tempos e; em caso afirmativo, qual dos sistemas seria mais adequado (MTM-1; MTM-UAS; MTM-MEK).

Os resultados permitiram verificar que o sistema MTM-UAS é mais vantajoso do que o MTM-1. Esta conclusão, adequada à produção em série e aos métodos empregues na unidade de Bosch Ovar, baseia-se quer simplicidade de uso quer na precisão dos tempos medidos. Os resultados não são extensivos a células de produção dada a complexidade ou mecanização de movimentos.

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Acronyms

BOM- Bill of Materials

BPS- Bosch Production System

CAPP-Knowledge- Computer Aided Production Planning- Knowledge

CIP- Continuous Improvement Process

ERP- Enterprise Resource Planning

IPS- Initial Production Start

MAE- Manufacturing Assembly Equipment

MOE6- Manufacturing and Operations Engineering 6

MTM-1- Method-time measurement: Basic Motions

MTM-2- Method-time measurement: Motion Sequences

MTM-MEK- Method-time measurement: MTM in the individual and small batch production

MTM-UAS- Method-time measurement: Universal Analyzing System

PCB- Printed Circuit Board

PQI- Production & Quality Instructions

THT- Through Hole Technology

TMU- Time Measurement Unit

SAP- Systems, Applications & Products in Data Processing

SMT- Surface Mount Technology

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1 Project introduction

1.1 Overview of the company

Bosch was founded in 1886 in Stuttgart, Germany, by Robert Bosch and two associates, who opened a “Workshop for precision mechanics and electrical engineering”. In the first years of business Robert Bosch produced all types of mechanical and electrical devices. The cornerstone of Robert Bosch´s success was the production of the first Bosch magnetic ignition for stationary internal combustion engines (Bosch logo present in Figure 1, is based on this device) and granted a good start for this company, which proceeded with constant innovation and development of new products. Nowadays Bosch has more than 360 subsidiaries in 50 countries, and is represented in 150 countries.

Figure 1- Bosch logo

Bosch production, research and development can be divided in four different businesses (Bosch 2015), as shown in Figure 2.

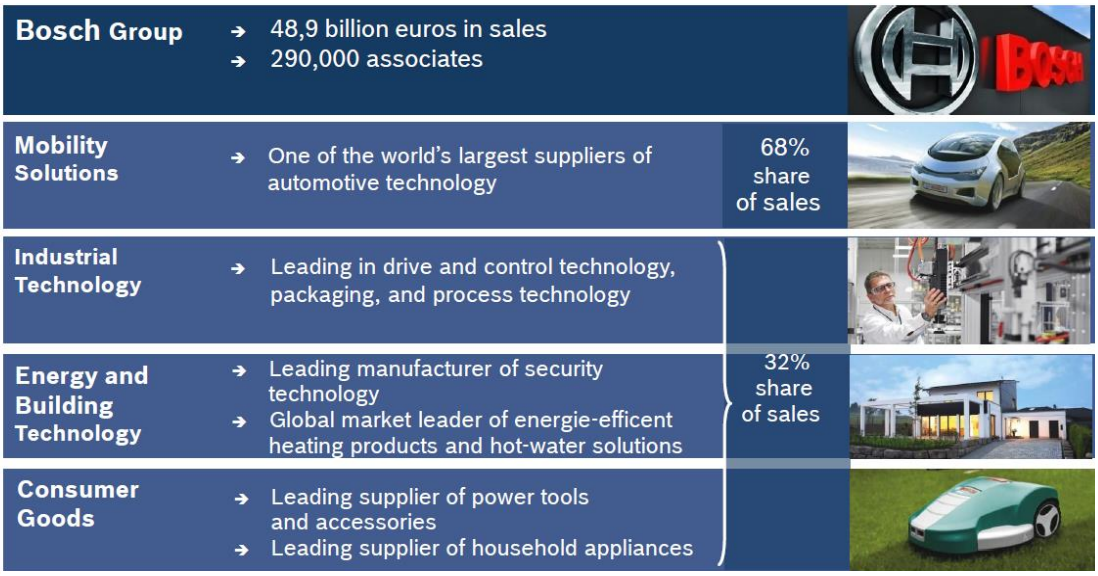


Figure 2- Bosch group sales percentages

From 2009 to 2014 the Bosch group invested more than 20 billion Euros in research and development, registering an average of 18 patents applications a day, of which anti-skidding system ESP or direct injection are examples of application areas.

In Portugal, Bosch has three production plants in Aveiro, Braga and Ovar, and a sales center in Lisbon. These plants produce various products from different product families, and Ovar in particular, manufactures products for energy (mainly thermos-technology), support to other industrial plants, like printed circuit boards assemblies of the Security Systems group and consumer goods such as the production of security cameras and communication systems.

The Ovar factory was founded in 1980, as Philips Consumer Electronics. From 1980 to 1993, the plant integrated new business areas, Sound and vision, with an establishment of Video Cameras Modules (1993) as a business unit. In 2002, Bosch bought the Ovar Plant to Philips.

1.2 Project framework and motivation

The project was accomplished in Bosch Ovar Plant, more specifically in the manufacturing and Operations Engineering 6 (MOE6) department, composed by a group leader and divided into three groups, as shown in Figure 3:

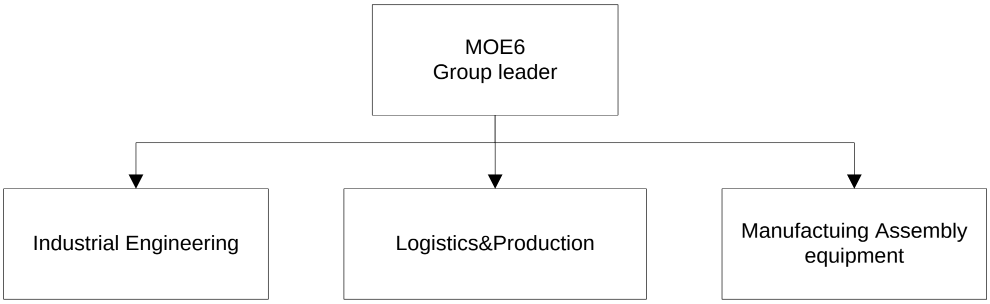


Figure 3- MOE6 organization

The department is responsible for, amongst other activities:

- Supporting the implementation of the Bosch Production System concepts;
- Definition and management of production standards;
- Cost reduction;
- Times measurement;
- Management of the material flow;
- Definition of the work cell layout;
- Ergonomics;
- Buying and managing the production equipment;
- Definition of the maintenance;
- Production capacity.

As the name “Study of method-time measurement system in an electronics assembly line” indicates, the main focus of the project is the identification of a method-time measurement system that best fits the company’s production, and posterior adaptation to production.

The objective of the project was well established: “The implementation of a method-time measurement (MTM) system, mainly for the implementation of new projects, with high production volume.” This objective was motivated by the targets of the Bosch Security Systems division, stating that until the end of 2015, all plants belonging to this group had to implement the CAPP-Knowledge and the Bosch Ovar Plant had as an objective finding suitable method-time measuring system.

1.3 Project at Bosch

The first stage of the project was the analysis of how the factory works, how it is organized as well as how the material and information flow works. In order to understand this, a Value Stream map of a high-runner product in the plant was drawn. This first analysis allowed the creation of contacts and to understand people responsibilities and working processes inside the company's structure.

The second stage was to understand how the production lines work, how the material replenishment is done and the standards and documents used to manage production. Only with the analysis and understanding of the previous processes will it be possible to update the documents used in the productive process, in order to include the use of a predetermined motion time system.

Bosch Production System, an adaptation of the Lean methodologies, considers only three different method-time measurement systems. Of these two, only two different method-time systems were studied: Basic Motions (MTM-1) and Universal Analysing System (MTM-UAS). The third method MTM-MEK, only applies to the individual and small production, and in this particular project, the main focus was on lines with high production volume.

Data like production volume, processes and production difficulties was collected in the work cells, company forecast and supporting documents. With this information, a matrix was created, in order to choose which system is most appropriate to each work cell. This new matrix was used and added in the new balancing template (document that controls the work load allocation inside the work cell), along with a template supporting the use of a method time measurement system.

A roadmap detailing how the information is documented in a new tool to the Bosch Ovar Plant was created, the new software being: *Computer aided product planning: knowledge* (CAPP-Knowledge), an add-on of SAP, an Enterprise Resource Planning (ERP) software.

1.4 Dissertation structure

This document is structured in five chapters. Following this introductory chapter, the next chapter incorporates a review of the tools and philosophies behind the project and a theoretical review of method-time measurement systems. It documents the elements of the Bosch Production System (BPS), including Lean tools, like poke-yoke or 5'S, determinant in the correct use of the predetermined motion time system. An extensive research on method-time measurement was performed, despite this effort, the number of reliable sources found was limited, mainly based on books written by the developers of the studied method.

In the third chapter starts with a presentation of the products and processes at the Bosch Ovar Plant. This includes a review of all processes, since the concept of the product, to its industrialization. This process dictates the operations and sequence of tasks the product will undergo when testing and production, so a simple explanation of this processes is necessary.

The process of industrialization is documented, and the templates examined and explained, templates directly affect the motion time measurement system used. A concept has to undergo a defined process, to analyze the risks of a product, both in its production and in the components that constitute the product. All the previous documents are registered in SAP, so it is also explained how they are introduced in the existing software.

The forth chapter is composed by two parts, it explains the steps followed during the project, fundaments in the decisions and some of the results obtained during the study of the factory. Then, it explains the new tools created to study chosen work cells, and the tools to organize the information with a SAP (Systems, Applications & Products in Data Processing) add-on names CAPP-Knowledge (Computer Aided Production Planning- Knowledge).

The last chapter is focused on the conclusions and observation of the project, an overview of method-time measurement systems and possible application of the method-time measuring system in other areas of the company.

2 Bosch Production System and method-time measurement systems

2.1 Lean in Production and Operations

Lean Production has a core principle: "Only produce what the customer requires." Although this seems a simple principle, it requires optimized processes, efficiency and standardization, in order to guarantee continuous improvement and sustainability. Bosch uses in everyday work an adaptation of the lean system, called Bosch Production System (BPS). Even though the principles similar to the ones present in Lean, the organization of the tools and the methodologies to the company are slightly altered, to be more adequate to the business (Bosch 2008). Bosch production systems principles consist of:

- Perfect quality;
- Process orientation;
- Flexibility;
- Pull system;
- Transparent processes;
- Standardization;
- Waste elimination and Continuous Improvement Process (CIP);
- Associate involvement and Empowerment.

These principles exist in order to meet an objective: deliver what the customer requires on time, with minimal costs and maximum quality, so the customer is satisfied and the company has the minimum costs possible.

2.2 The meaning of perfect quality

The concept of "perfect quality" may seem vague, although it has a very specific meaning within the Bosch production and operating philosophy. Perfect quality in production means that the final product fulfills the exact specifications promised to the customer, being exactly what the customer required. The customer wants a product with perfect quality, so the company has to find a method to this end, taking into account the costs of the process, which requires constant overlook over the processes and product quality.

To reduce the costs, there is a need of eliminating operations without added-value (waste). According to lean, waste can be divided in three categories: *Mura*, *Muda* and *Muri (Japanese)*, which direct translation is poor timing, waste and overwork. These three categories are dependent on the area used, stocks, routing, transportation costs, waiting times, overproduction or repairs/faults.

Overproduction results in less product quality, additional stocks, and consequently higher costs, increase support costs and problems with the product delivery/information (Bosch 2008). The definition of “Perfection” according to Bosch Production System can be understood and expressed quoting Antoine de Saint Exupéry on “Terres des Hommes”: “*Perfection is achieved not when there is nothing more to add but when there is nothing to take away*” (Saint-Exupéry 1939).

2.3 Transparent flow and process-orientation

The objective of taking into account process orientation is to create a flow-oriented process, self-controlling and regulated (Bosch 2008). Flow can also be analyzed in three subgroups, in accordance to its adaptation for:

- Collaborators: in order to achieve a correct workflow, processes need to be stable and synchronized with a clear rhythm (usually established by the cycle time or customer takt time);
- Materials: they need to have a clear routing and information needs to be clear and transparent, so a change of any parameter becomes evident;
- Information: it needs to be simple and available clearly for the correct people, and easily updated.

2.4 Flexibility in both production and people

Flexibility is key in a lean production system. It allows processes to be updated faster. Minimized set-up times allows various products to be manufactured in the same line, and consequently produce smaller series. Optimization can also be done by changing processes within the work cell, for example, changing the order of an assembly (Bosch 2008). Flexibility can be verified in many aspects as shown by the following examples:

- Machines and equipment: machines running-times, set-up times, space requirements or manufacturing tools;
- Associate adaptability to other environment/ work methods;
- Flexible but still stable logistics, with changing transport routes or supply cycles;
- Organizing product flexibility from the quantity to component variation.

2.5 Only produce what the customer will buy

In the past, a majority of the companies’ production would follow a push-system. Push-system is forecast oriented, and there is an entity within the company responsible for the planning and control of the production, three business units (chapter 3.1) that control the Bosch Ovar Plant demands, resulting in a centralization of power.

The main problem with the push system is customer demand, which is not stable, fluctuating throughout time, and in order for the company to keep up with this rhythm it would need to have large amounts of inventory, to answer the customer needs. Other problem would be the forecast inaccuracy, which forces the company to change planning. All this problems would have its costs, like for example, the cost of stock (both in the space required to hold it, cost of holding inventory and damaged goods), capacity problems or utilization costs, since many of the lines would be inactive due to low forecast of its products.

Since this system was flawed, a new one, named pull-system, was developed by Taichii Ohno. The main difference is that it is consumer oriented. Production being consumption oriented leads to stable inventory levels, since there is only a need to replenish the stock. The customer needs fluctuates throughout time, so the company can’t keep producing the same amount for each product. So there was invented “leveling”. Leveling consists on leveling the production of each product throughout time, according to the customer consumption, with a final objective of elimination stocks altogether.

This results in flexible manpower, standardized processes and stable work load in production. The push-system is still used in the present, but companies' development leads to the pull system, in order to have lower costs and better lead times (Bosch 2008).

2.6 Importance of standards in continuous improvement

Every company has to improve in order to stay competitive, but improvement through innovation can be tricky. It frequently requires a lot of resources and time, and often the results are not what is expected with the inherent trial and error procedure.

According to BPS, there can be continuous improvement with little to no investment, when clear goals have been defined. This improvement is achieved with small steps and intensive associate involvement (not considered waste, since some changes add value). But even with low investment, improvement has to be sustained, therefore the creation of standards. Templates are created to guarantee that, when success is achieved, the process doesn't fall back to the initial state.

The creation of standards can be related to many subjects, from how employees are supposed to act, to how to plan production (Bosch 2008). There is a need for test the work cell, for example what processes need to be reviewed, and how to do the replenishment of raw-material or material from other lines. In order to do these tests, BPS recommends a five stage system, called sample runs. Throughout the runs, the processes can be changed and optimized.

2.7 Adaptation of lean to Bosch – Bosch Production system

Bosch Production System (BPS), an adaptation of both Lean, in order to respects its principles, adopted and developed tools, some of which directly affect the use of a MTM system, or force adaptation of the system. Some of these methods are:

- 5S's;
- Flow-oriented layout;
- Poka Yoke.

Have a fluid system with the correct organization (flow-oriented layout)

5S's methodology is often considered just common sense, however the degree in which it is applied is very relevant. Figure 4 demonstrates the fundamentals of the 5S methodology:

Figure 4- Fundamentals of the 5S methodology

The 5 words present in Figure 4 are a simplification of the true purpose of this method, which correctly explained means that the workstation must only have what is strictly necessary in it, everything must have a clear location and be correctly placed. The work place should be also clean, standardized and people have to be self-disciplined to control the workstation. At Bosch, each department is responsible to evaluate the condition of each workstation, using a specific enquiry, a template created for each section of the factory. The check-up is done monthly, which results in a clean and well-organized plant.

There are doubts that arise when trying to implement this method, "Will sorting and arranging increase the results*?"* or *"*Why should we clean since it gets dirty again?" (Titu, Oprean, and Grecu 2010). From previous tests and experiences it is noticeable that these methods can have very positive results, and there needs to be a clear organizational system for this method to work correctly (Titu, Oprean, and Grecu 2010).

Poke-yoke

Poka Yoke direct translation means "mistake-proofing", methodology that in the past was called Baka Yoke or "idiot-proof". Essentially, it relates to the techniques used to avoid inadvertent mistakes (*yokeru*) (de Bucourt et al. 2011), from human to mechanical errors. These errors can occur in different stages of the assembly, like processing, setup or operations errors or even missing parts. During the product development, it is checked what mistakes can be corrected, focusing mainly on the assembly. For example, when assembling a component, if it can be inserted in more than one way (called polarity at Bosch Ovar Plant), the Poke Yoke methodology states that it must has clear instructions or an indication on the component, to ensure that it only assembled in the correct position, in order to prevent incorrect assemblies. To also help the assembly, supports for it are made, so ensure that the product doesn't move (mainly when performing precise movements) or to indicate where a component must be fixed. Figure 5 represents a jig where a PCBA is placed, with pins, to stop the component movement, preventing eventual mistakes.

Figure 5- Pratical exemple of the Poka Yoke methodology

2.8 Method-time measurement systems

In the last 100 years, industrial revolution led to creation of many new production standards, like mass production or batch production, to new methodologies like 5S or the Value Stream Design. The thirst for profitability, led to minimization of costs, not just in production, but also in planning and development of products. The early days of Industrial Revolution awoke the need for mechanization, automation and work organization. With this fast technologic evolution and intense competition, there was a need to study how to optimize processes and their timings, and consequently the study of motion began.

Several people started researching and testing, amongst them Frank Bunker Gilbreth or Frederick Taylor.

Method-time measurement systems associates each human movement to a specific time, result of years of motion study and measurement. Knowing the movements of a worker in a production line, the times obtained after observation allows planners to have an estimative of the timing and therefore, to be more efficient. There are many kinds of method-time measurement systems, and even within a single factory it's possible to choose between different systems.

The later ended up creating a new "philosophy" named "Taylorism", or scientific management based on the efficiency of work processes. According to Taylorism, tasks, work method and necessary time all have to be defined so the process is optimized. Taylor is famous not only for his work, but his research, having written books about the matter, amongst them "*The principles of Scientific Management*".

2.9 Different methodologies to determine method and times measurement

MTM systems are in constant development, but all have in common a basis derived from the first, MTM- Basic Motions (MTM-1). All the systems have some common points, more specifically (Directorate 2015):

- The method must be applicable in every industry;

- The method must be generally comprehensible and easily learned without any particular previous knowledge;

- The method must be designed in such a way the execution time for a given method is "automatically produced";

- The method must be managed in an identical fashion around the world.

"Predetermined time systems require detailed analysis of the current method of an operation. So, standard workflow of this operation is defined. Each motion of the operation must be analyzed. This detailed approach makes it easy to find out obvious problems and non-value added motions*"* (Cakmakci and Karasu 2007).

Time measurement unit

Method-time measurement system is a quantitative method, with its own measuring unit. The unit of MTM is called TMU (Time measurement unit), and it is defined by using the formula (2.1) (Amer 1957):

$$\text{TMU} = \frac{1\,hour}{360000} \tag{2.1}$$

With this measurement unit it is possible to be more precise estimating movement times.

Movement sequences difficulty has to be decomposed between work method and method degree, each one answering a different question. On one hand, within work method, it is analysed what are the sequence stages, in order to answer the question "What is the movement sequence".

On the other hand, there is a need to study task adaptability: "What quality does it have". Workers with higher experience level and higher quality of job organization/standards level mean higher method degree. Method degree depends on skill and equipment required (Cakmakci and Karasu 2007).

There are several method-time systems, but the ones applied by the Bosch Security Systems are:

- MTM-01;
- Method time measurement- Motion sequences (MTM-2);
- Method time measurement- Universal Analyzing System (MTM-UAS);
- Method time measurement in the individual and small batch production (MTM-MEK).

Movement complexity

Movement complexity is established by defined criteria. There is a clear difference in details between systems. The depth of main criteria differs in the following way:

- **Information about the work order ,** which can be characterized in 5 different ways:
    - Movements, a single motion;
    - Movement sequences, already composed by more than 1 movement;
    - Basic processes, that are composed by different movement sequences;
    - Tasks, composed by many basic processes, for example, assemble an object;
    - Complete production, which is just the description of the production of a new product.

An example of the difference between a movement and movement sequence is: in MTM-UAS there is a movement called "Reach and grasp", while the same movement is divided in two separate motions using the MTM-1 system, "Reach" and "Grab". Using the MTM-1 system, the movement can be highly detailed, and if the workers motions are highly repetitive and mechanized, it results in precise results. However, this has its flaws, when doing the description of a process with high cycle times, movements can be inconstant, which results in incorrect movement specification, and therefore the system is not applicable.

- **The workers' difficulty to perform a certain task**. Tasks can have different variables, from the cycle time of a product to the specialization of the worker performing it. However when using the MTM system, the first step the user has to define is the degree of specialization according to the following variables:
    - Movement sequences with low cycle times;
    - Movement sequences with high cycle times;
    - Cycle times within workstation with low variation;
    - Cycle times within workstation with high variation;
    - Specialized area.

These categories will affect how many times a product is done, how many times the movement has to be performed. When doing the MTM system on movement sequences with low cycle times, often is highly repetitive, fact that demands more precision. The concept of low/high cycle times or movement variation has to be quantified, so the right choice is made.

- **Material replenishment on the workstation**. The way workers have to get the required material for the assembly can also be divided in three different ways:
    - Push principle, when the production material is supplied by other worker, and the person responsible for the assembly has everything close;
    - Pull principle, material is carried to the work place and the worker has to get it from the correct place;
    - Search principle, when the workers have to search for the materials used on the assembly.

- **Workstation configuration**. Organization in the workstation is very important, affecting the number of setups in the workstation.
    - o Detailed configuration for a single movement sequence;
    - o Configuration for product variations. Different workstations, with specialized and standard;
    - o Standard workstation;
    - o Universal workstation;
    - o Workstation without any characteristic configuration.

If search principle applied or the workstation is lacking any organization, times obtain while using the MTM system are not reliable, since components don’t have a fixed place and the extension of the movements to obtain it are not constant. The search for components can also include visual observation, which requires the complementation of the analysis with another MTM system. Figure 6 summarizes the relation between the work level and method are related to MTM-systems (Cakmakci and Karasu 2007).

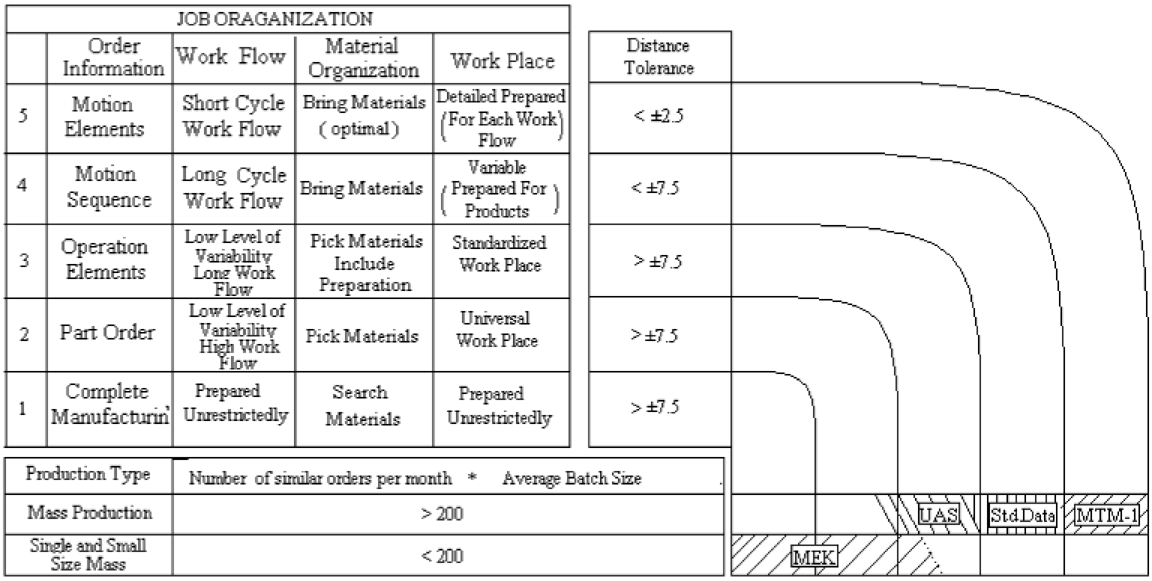


Figure 6- Relation between the job organization and system used (Amer 1957)

The MTM systems enumerated before are not applicable when the process involves mental activity, to be more specific, decisions beyond yes/no, so processes have to be correctly defined.

Usually it is used with products with small cycle times, and with defined motion sequences. It is composed by 17 movements, named *Therblins* (after Gilbreth): Reach, move, grasp, position, release, apply pressure, disengage, turn, foot movement, leg movement, side step, turn body, bend, sit, bend on one knee, bend on two knees, walk (Lesperance 1953). This range of movement allows a clear description allows for a concrete and structured description of the operators movements in their respective workstations.

Since this system is the most complex, it is suited in mass production, in which each workstation is well defined, workers movements highly repetitive and the cycle times are usually optimized. Each process, like pick up a pen is divided into a succession of movements, in this case reach and then grab the pen.

When it comes to the MTM-UAS, movement incorporate various motions present in the MTM-1 system. However it is more appropriate for batch production, since this system is based on different principles, present in Figure 6. MTM-UAS movements are divided into eight groups:

- Reach and grab;

- Position, when an object has to positioned or aligned in a specific position, with a specific tolerance/distance;
- Handling using other methods, if there are used specific objects to do a task, like a wrench;
- Actuate, in the cases that it is required to activate a motion, using hands or the foot. This motion can be done with a simple movement or a complex activation;
- Movement cycles, which describes cyclical movements performed using the hands, feet or fingers;
- Body movements, including walk, bend, kneeling or sitting and getting up;
- Visual control;
- Basic Procedures, numerous movements usually used in the production of a product. This includes unpacking, treat (clean, use glue or paint a product), fix/release, mount electric cables, write, mount normalized products, examine/measure or work with screws.

The later, Basic Procedures, proved to be very relevant when choosing the correct method-time measurement system to use at Bosch Ovar Plant, since it allows standard times to complex operations, in which the use of MTM-1 may be imprecise.

Specifications and coding

Precision in the MTM-1 system is very important, factor that also has to be on the user mind when analysing a process. Movements are not only characterized by the name, like “Reach”, having to be specified. When describing and coding the “Reach” motion, it has to be defined the tolerance of the movement, if the object reached is hard to reach, or its position is well defined or agglomerated with other components and the length of the movement.

As it is easily noticeable, and since there are fewer movements than in MTM-1, the times will be less precise but the movements’ sequences still are detailed. The level of detail expressed in code between the systems differs too.

For example, there is a significant difference when coding the length of movements. Using the MTM-1, the length varies by 2 units, like 2, 4 or 6 centimetres. In the case of MTM-UAS, lengths are expressed in 3 sections:

- 1, when the lengths is inferior to twenty centimetres;
- 2, from twenty to fifty centimetres;
- 3, when it is superior to fifty centimetres.

In the case of mass production, when workers movements are constant and precise, it is possible to measure a very specific length for each movement. If the movements are not that exact, the code won’t calculate the best time, and sometimes, the use of MTM-UAS is preferable.

When all this characteristics are assembled, it is codified, in an internationally defined structure, like for example:

(m) R 20 A (m) = 7, 8 TMU

The code above can be divided in four parts for a better understanding:

R - It is a reach (R) movement, in symbolizes the motion in which people extend the arm to reach some object;

20 - The movement has a length of 20 centimetres;

A - The object is in a fixed position, and the person reaching it already has some practice, or the object is in the other hand (being the distance between the hands inferior to 7,5 centimetres.

(m) (m) - On this movement is also possible to code if the movement is constant or there is an acceleration, the (m) is positioned as a prefix to the code, or slowing down, when the (m) is a suffix.

The “reach” (R) movement has five different specifications, symbolized with a different character (in this case, A), from A to E, and each of them have different time values. For example, B means that the “*Movement of the empty hand requiring visual control and terminated in space by muscular control*” or, in the case of the movement being characterized as R_C, it is described as: “*Movement of empty hand requiring no visual control and terminated by grasping an object. Usually the movement is in a fixed location or in the other hand*” (Amer 1957).

There are other rules that need to be respected in order to code the correct movement, like for example (applied to the reach movement): “If the hand movement is shortened by additional body movements, this distance has to be subtracted to the total body movement.” (Amer 1957).

Each movement has a set of rules like the one mentioned, that need to be follow it in order to code it. The result of the movement is then calculated according to table obtain by the observation and study of movement sequences, for example, R20A takes 7,8 TMU to be performed.

In other systems, the movements are derived from the MTM-1 system. For example, the MTM-UAS are a combination between MTM-1 motions and rules (MTM-Vereinigung 2005).

“Reach and positioning” is one of the MTM-UAS movements, which includes, the MTM-1 movements’ reach, grab, move and position, and can be coded as:

A F 2 = 65 TMU

To be clear, it’s better to split the code:

- The letter “A” means it is a “Reach and position” movement.
- “F” is more specific. It expresses that the weight of the component is less than a kilogram, it is difficult to pick up and the tolerance to grab it (position of the object) is smaller than 12 millimetres.
- The distance is named 2, as it was said before, is between 20 and 50 centimetres (MTM-Vereinigung 2005).

This is the data needed to code a MTM-UAS “Reach and position” movement, although it can change, affected by other elements, which variations can be:

- Difficulty to perform this task, considered “hard” when the movement requires preparation, like rolling a cylinder, or caution when moving a sharp object;
- The weight of the object;
- Distance tolerance, also represented in Figure 6;
- How the object is stored (proximity and organization of components, as can be seen in Figure 7).

Figure 7- Example of material organization on a workstation

Principles of motion economy

Gilberth created a list of twenty principles of motion economy, to help analyse a process, in order to minimize the waste. The principles are divided in three different subdivisions: Use of the human body; Arrangements and conditions of the workplace; design of tools and equipment; supplementary rules for analysis procedures. Amongst other principles, the ones considered relevant to the project are (Morrow 1946):

1. *"*Use simultaneous arm motions, in opposite and symmetrical directions*";*
2. *"*Avoid sharp changes of direction. Plan a smooth motion path*";*
3. *"*Slide small objects. Avoid pick up and carry*";*
4. *"*Locate tools and materials in proper sequence, at fixed work stations*";*
5. *"*Shorten transports by keeping materials nearby in gravity-feed hoppers*";*
6. *"*Pre-position tools for quick grasp*";*
7. *"*Provide pleasant working conditions, considering illumination, temperature, humidity, dust, fumes, ventilation, noise level, color scheme, orderliness, and the like*."*

These principles directly affect the time of the process, and the creation of the motion time measurement systems provided a way to document the time savings. They are directly related to other BPS tools or philosophies, like the 5's (principle 4 and six) or flow-oriented layout (principle 5).

When trying to solve a problem, it is possible to use the 5W2H technique, asking 5 questions about the problem: "What?"; "Why?"; "Where?"; "When?; "Who?"; How?"; "How much?" (Ploix and Chazot 2006). Likewise, when evaluating operations, these have to undergo 4 different tests (Morrow 1946):

1. "Can the operation be eliminated?"
2. "Can it be combined with some other operation?"
3. "Can we use a better sequence of operations?"
4. "Can it be simplified?"

3 Plant organization and study of processes

3.1 Know the company- Value Stream Map

The first task at the Bosch Ovar Plant, there was to understand how the company works, how it's organized, what products are manufactured, and tools used. In order to achieve a global insight, a Value Stream Map (VSM) was done of a representative product, a HD surveillance camera, high-runner in the plant (Kepler HD). The VSM gave a global understanding of the processes involved, of their interconnection and its limitations.

The first step when doing a value stream map (Figure 9) is recognizing the flow of material and information. The factory produces to three continental distribution centers, one in Tilburg (Netherlands), Europe, other in Singapore (Singapore), Asia and the last one in Lancaster (USA), North America. These business units needs control the production output in the Bosch Ovar Plant, and are responsible for the final product distribution to the end customer (Figure 8).

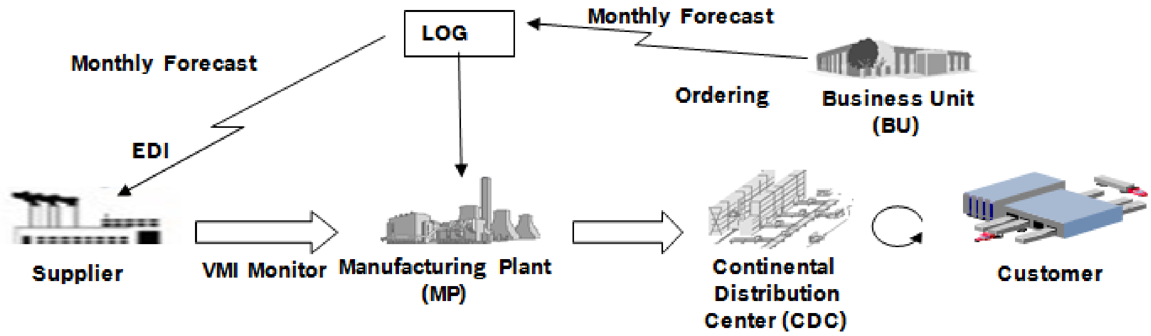


Figure 8- Business unit- Bosch Ovar Plant relation

The business units act as supermarkets with the following characteristics:

- Replenishment of products;
- Safety stock;
- Demand products from the business unit.

In order to satisfy demands from the referred business units, the needed raw materials/component has to be available at the Bosch Ovar Plant as safety stock

The VSM information flow was then analyzed. Orders are receive, they are put daily in production line by planning in a Heijunka board[1] (pattern with sequence of production) with yellow kanbans cards that represent the product. The production line works as a *pacemaker* for the whole production process, as it establishes the rhythm.

[1] "Heijunka is a key-element of the Toyota production system which levels the release of production kanbans in order to achieve an even production flow over all possible types of products, thus, e.g. reducing the bullwhip effect" (Matzka, 2012).

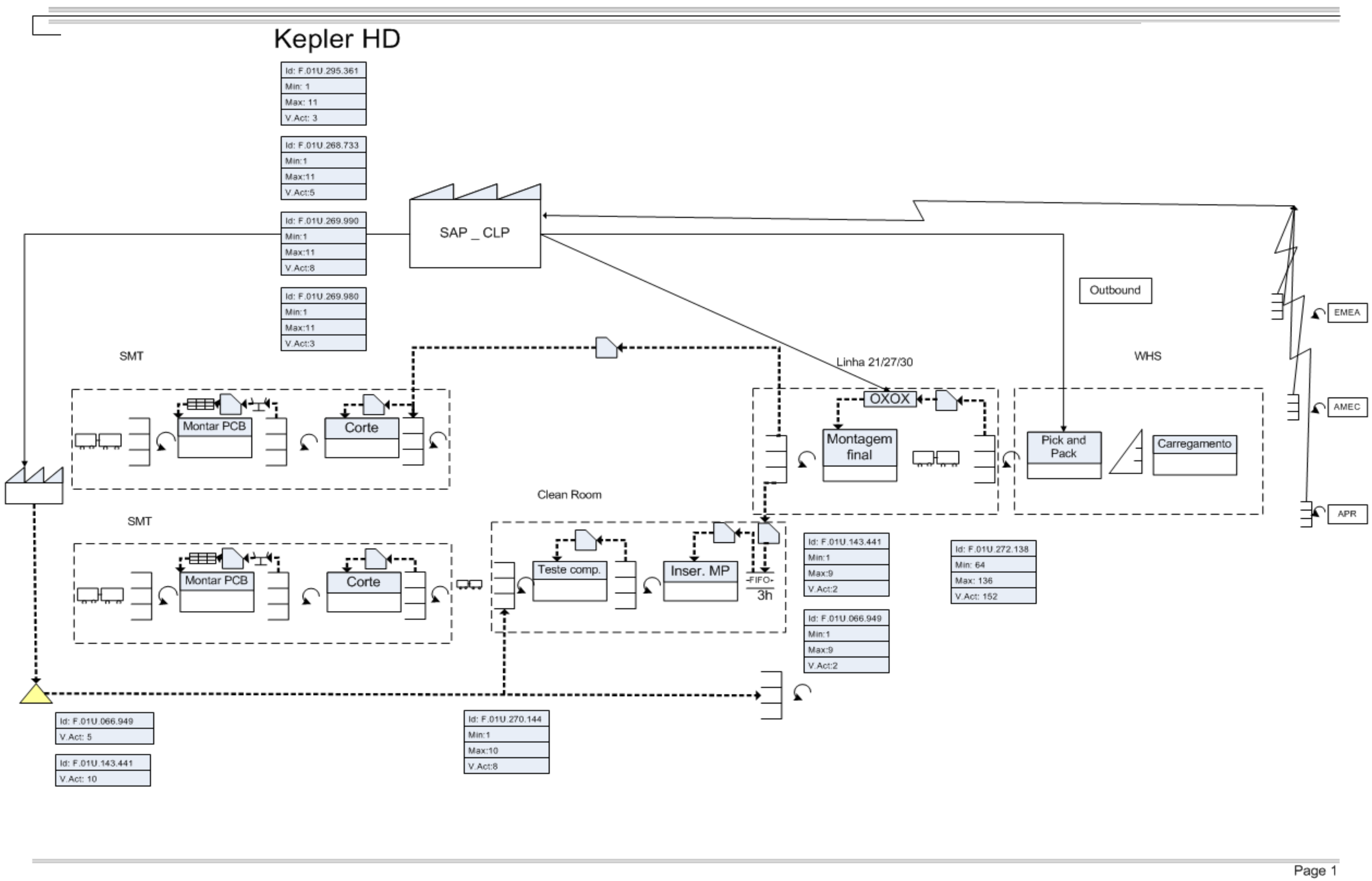


Figure 9- Value stream map of a Kepler HD

As for the material replenishment to the production lines, at the Bosch Ovar Plant the raw material flow, through milk-runs, from the main warehouse to the supermarkets placed near the lines, represent by blue Kanban cards. The line supply is made by POUPs (Points of Use Providers). The use of POUP brought many benefits to the plant, such as the possibility to prepare the materials in advance to the line, in order to answer the needs of high diversity of products and to optimize production line on changeovers.

For this specific product, the Kepler HD surveillance camera, assembly of the product in a work cell, with different processes, welding, testing and regular assembly. The POUP has to pick semi- products from internal suppliers (PCBA) in 3 sections of the factory, Surface mount technology (SMT), Through Hole Technology (THT) and the Clean Room and bring Yraws (products from the warehouse, that don't require previous treatment) from near supermarkets to the workstations. There is standardize work define for this process in all plant.

The final products are then transported to the warehouse, where they go through a "pick and pack" process, and then stored in a point of inventory, until they are sent by the business units.

Bosch has presently 3 value stream managers, each one responsible for the material and information flow in the value streams (chapter 3.2). There are several tasks to be managed, e.g.:

- What problems need to be solved;
- What's their priority;
- What operative flaws have to be corrected and how they affect the system.

Value stream managers are responsible for the value stream of families of products, for the production process, from the suppliers to expedition, and to accomplish this different tools are, as for example the value stream maps. In VSM all potential improvements, inventories etc. are highlighted and this gives place to a Value Stream Design (VSD) with projects improvements.

3.2 Products

Bosch Security Systems at Bosch Ovar Plant manufactures a wide range of products and operates in a world-wide structure. In order to assure the plant´s organization and effective communication with other business units and customers, products follow a specific organization: each product is specified by a code and belongs to a family. Different families can be attributed to a value stream, due to product similarities, and the processes necessary to manufacture it (Figure 10):

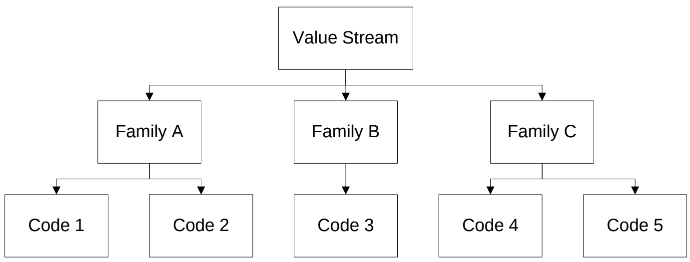


Figure 10- Demonstration of the product organization

The difference between codes can be significant, changing the most important components on the product, or can be less relevant, just changing accessories of minor importance.

To be more specific, the value streams at the Bosch Ovar Plant are:

- Video;
- Extreme Video;
- COMM;

- Thermo Technology. (TT)
- Fire.

Table 1 presents the different families that constitute each one the value streams, the number of different products produced and in how many work cells are at use. Some of these products may not be in continuous production, and thus implies production restart when needed.

The Bosch Ovar Plant uses diversity of products as a business advantage, however this makes planning harder, and many work cells undergo numerous setups during one day.

Table 1- Characterization of value streams

Value streams	Nº of families	Nº of products (codes)	Nº of work cells
Video	>20	>100	>5
Extreme Video	>20	>100	>5
COMM	>20	<100	<5
TT	<5	<25	<5
Fire	<5	<25	<5

The following Figure 11, Figure 12, Figure 13 and Figure 14 present some of the products manufactured at Bosch Ovar Plant:

Figure 11- COMM family router

Figure 12- Extreme video family camera

Figure 13- TT family product

Figure 14- Example of Video Cameras- Video family

As shown in Table 1, there is a wide variety of products for the number of lines available, Bosch Ovar Plant has low volume high diversity in a project oriented business thus flexibility is very important. Only two new work cells on the Bosch Ovar Plant are focused in semi mass production, while the other twenty seven work as batch production (date: March 2015). The previous information leads us to understand the importance of setup times and precise planning, in order to reduce waste and to ensure that the plant keep up with the production requirements.

Beside these value streams, the plant also produces assembled printed circuit boards (PCBAs) to other Bosch plant.

3.3 The Manufacturing Engineering Process

Manufacturing Engineering Process (MEP) refers to the succession of event since the product concept to the industrialization of the product. Several processes need to be undertaken before the product production such as establishing the supply chain, financial control, administration process, human resources management and manufacturing processes. During the product production other processes are associated such as continuous improvement, preventive actions, control of non-conform product and corrective actions, preparing equipment and infrastructure management.

The MEP executes the Product Engineering Process that undergoes defined steps:

- Orientation;
- Definition;
- Development;
- System test;
- Launch;
- Volume production.

From the product orientation to its definition, a first prototype is done, named A Sample. This product is used to do the test documentation and to identify the critical component list.

After the A-sample, there is an evaluation of the results (QG0, Figure 15)[2], using analytical tools, like product risk analysis or failure mode and effects analysis. At this point, an industrialization contract is signed. This is followed by the production of a B-sample that is submitted to another quality gate, (QG1 , Figure 15) that leads to technical specification that include the requirements verified based on B-sample, the defined sub-suppliers and the release of the C-samples.

The next step between gates is called system test phase, and another production sample is performed, usually with the production of several units. This test is a preparation for the initial production start that occurs from the fourth gate to the fifth. At this phase, products processes, supply chains have to be documented.

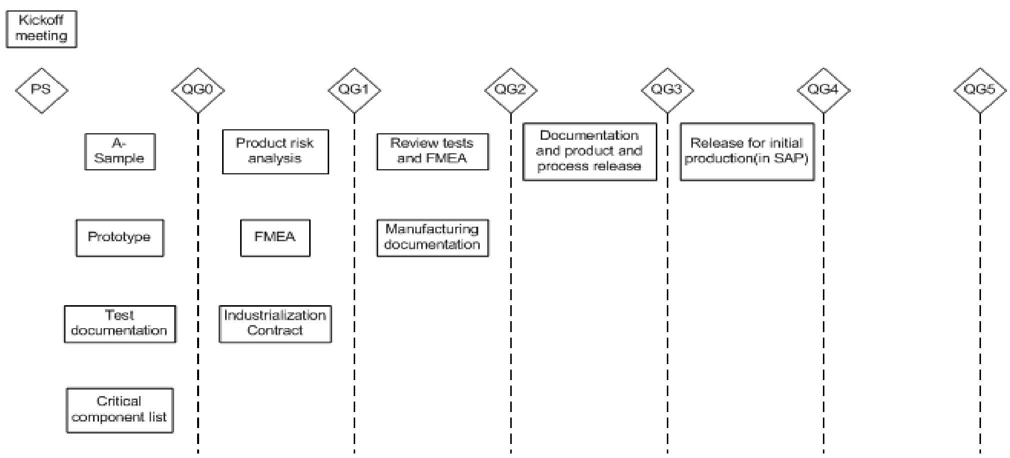


Figure 15- MEP process

[2] QG meaning Quality Gate

3.4 New product implementation in the industrial engineering department

When a new product is implemented, there are several steps the plant has to follow.

Although each product is influenced by every department, the main focus of this project is the Manufacturing Operations Engineering (MOE6) department, since the department is responsible for the lines manufacturing processes, balancing and measuring systems used.

MOE6 is composed by 3 different internal groups, industrialization, internal logistics and Manufacturing Assembly Engineering (MAE). Industrialization takes care of the processes inside the work cell, internal logistics is responsible for the control of the replenishment of materials in each line and MAE is responsible for the creation and maintenance of the jigs (custom-made tool used to control the location, by stopping eventual motion, of another tool (Henriksen 1973) (Figure 16), as well as for the tools used in the work cells and the workstations.

When the line is being prepared, to manufacture a new product, there are several things MOE6 has to take into account, like the housing (line structure and building), or to define the Production and Quality Instruction (PQI) for each workstation.

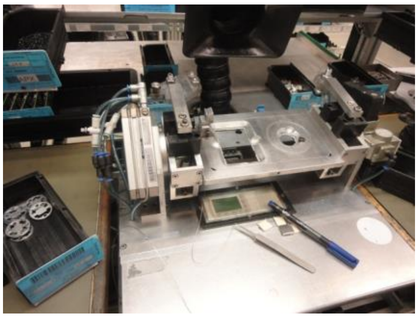


Figure 16- Example of a JIG with an automated system

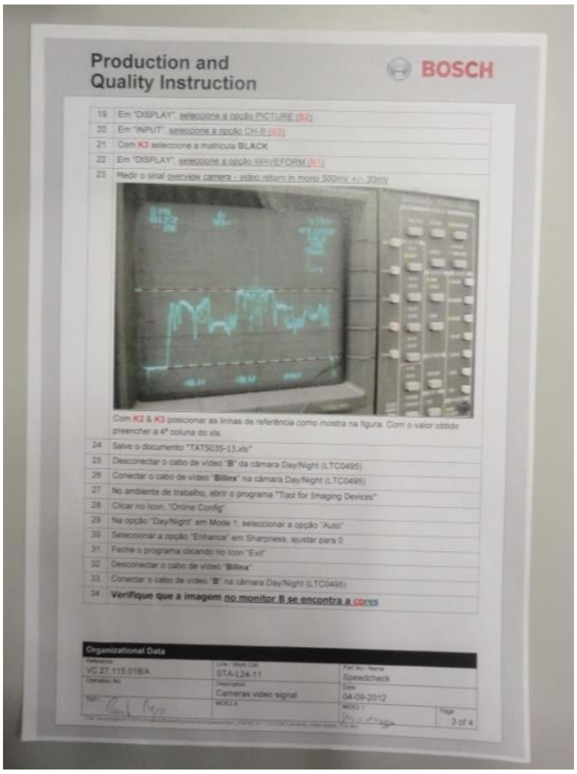
Several aspects influence the time necessary for the production of a product. For example, if the material replenishment isn't done correctly, the line will eventually stop; if the PQI isn't correct or the tools or if the jigs created aren't adequate, the final product will not fulfil the customer requirements.

Planning the manufacturing areas includes the positioning of supermarkets (there can also be FIFO routes or inventory points), areas for deliveries, according to the line needs and space requirements.

The process of industrialization requires the creation of standards and templates, defining the plan the line production. Processes in the workstations need to be established and tasks allocated to workers. For that, templates were created, with a specific set of rules, more specifically PQI's (Production & Quality Instructions), Balancing sheets and STABs (document that determines the route of each worker within the work cell).

3.5 PQI's (Production & Quality Instructions)

PQI is the abbreviation of Production and Quality Instructions, a document detailing the standard work sequence and instructions to avoid errors in production. If a component has specific limitations, the PQI has to indicate what problems it can create, and how it can be assembled without damaging the final product. Figure 17 is an example of a PQI present in a workstation, in which a product has to be tested using an oscilloscope, which the expected results.


Production and Quality Instruction

BOSCH

19	Em "DISPLAY", seleccione a opção PICTURE
20	Em "INPUT", seleccione a opção CH-B
21	Com K3 seleccione a matricula BLACK
22	Em "DISPLAY", seleccione a opção WAVEFORM
23	Medir o sinal overview camera - video return in mono 500mV +/- 30mV
	Com K2 & K3 posicionar as linhas de referência como mostra na figura. Com o valor obtido preencher a 4ª coluna do xls.
24	Salve o documento "TAT5035-13.xls"
25	Desconectar o cabo de video "B" da câmara Day/Night (LTC0495)
26	Conectar o cabo de video "Bilinx" na câmara Day/Night (LTC0495)
27	No ambiente de trabalho, abrir o programa "Tool for Imaging Devices"
28	Clicar no Icon, "Online Config"
29	Na opção "Day/Night" em Mode 1, seleccionar a opção "Auto"
30	Seleccionar a opção "Enhance" em Sharpness, ajustar para 0
31	Feche o programa clicando no Icon "Exit"
32	Desconectar o cabo de video "Bilinx"
33	Conectar o cabo de video "B" na câmara Day/Night (LTC0495)
34	**Verifique que a imagem no monitor B se encontra a cores**

Organizational Data

VC 27 115 018/A	STA-L24-11	Speedcheck
	Cameras video signal	04-09-2012
		3 of 4

Figure 17- Example of a PQI

There are other aspects in a PQI, like organizational data, quality instructions and time expected for the workers of the workstations to complete all tasks. Organizational data is constituted by the work cell and PQI codes used in the work cell. Quality instructions are used to register a possible defect, its origin, its detection, response limit and remarks about it.

3.6 Balancing

Balancing is the template in which the MOE6 department documents the times measured in the work cell, with the final objective of balancing the work load amongst the operators. With the times measured, the calculation of the capacity required and the operational time, the number of operators in the work cell is calculated, as well as the production capacity (dependent on the number of workers in the work cell and the work allocation amongst them. To know these values there is a need to know the time available in the line.

Before knowing times for each line, there is a need to know what is the customer takt time and planned cycle time. First, it is determined the number of shifts in which the line is active. The net production time is achieved using the formulas (3.1), (3.2) and (3.3). With the values calculated before, it is possible to get the customer takt time and planned cycle times, using the formulas (3.4) and (3.5).

$$Net\ available\ time = \sum Shift\ time - Planned\ stoppages \tag{3.1}$$

$$Operation\ time = Net\ available\ time - Rest\ personnel\ time \times Net\ available\ time \tag{3.2}$$

$$Net\ production\ time = Operation\ time - Quality\ losses \tag{3.3}$$

$$Costumer\ takt\ time = \frac{Operation\ time}{Demand} \tag{3.4}$$

$$Planned\ cycle\ time = \frac{Net\ production\ time}{Demand} \tag{3.5}$$

Time measurement is required to estimate the time of each workstation in the work cell, a sum of processes. The tool used at the start of the project in every work cell was the chronometer, and even though it can be a fairly accurate instrument, several factors can influence the measurements, such as the experience of the person performing the time measurements or the working skills and agility of the person performing the task at the workstation, mainly when the production is being planned (chapter 3.3).

There are other aspects can influence the time measurement such as changes of the processes, that require the measurements to be repeated. When testing the production of a new code, times of each workstation are taken several times (usually a sample size of 20) and registered, in order to establish time these take.

The times measured using a chronometer are registered in a specific spreadsheet that calculates the average time and standard deviation. The average of values obtained is used in the final balancing sheet.

Processes for each workstation is timed, in order to define how many operators are. The workload amongst workers is only then distributed. This calculation takes into account needed people (3.6), the available capacity (3.7) and the unbalanced percentage (3.8).

$$Needed\ people = \frac{Cycle\ time\ on\ the\ workstation/Operation}{Planned\ cycle\ time} \tag{3.6}$$

$$Available\ capacity = \frac{Net\ production\ time}{N^{o}\ of\ people\ \times Planned\ Cycle\ time} \tag{3.7}$$

$$Unbalanced\ percentage = \frac{N^{o}\ of\ people\ in\ the\ work\ center}{\sum Needed\ people} \tag{3.8}$$

Usually the balancing of the Bosch Ovar Plant is recalculated until the unbalanced percentage is close to 10%, which is considered optimal. The number of products prepared per day is given by the minimum available capacity.

The balancing template isn’t presented in this document to maintain the company’s confidentiality.

3.7 STAB

STAB, exemplified in Figure 18 is the attributed to the graphic explanation of the path each worker has to do in a work cell, the set of tasks to be undertaken at the workstation and the flow of the product with the respective drawing of it. This document constitutes a visual explanation of the work cell, with a drawing of all the workstations, supermarkets, tests and eventual obstacles inside the line (chairs, tables or final product location for example).

The data needed to build this document also includes, the number of operators, the tasks each operator has to develop as well as the time needed to go from on workstation to another. These document enables each workers inside the work cell to know what workstation they have to perform and the correct order to move while fulfilling their tasks.

Figure 18- STAB sheet on a work cell

The industrialization planner and line leader are responsible for the monitorization of the correct use of the STAB, and to and identify possible improvements.

3.8 Analysis of the production in the company

Each work cell produces many finished products, with an average of 16 different codes. The difference between codes can be just the appearance of a component, or a completely different PCBA (Printed circuit board assembly). The line with fewer products only produces a single code, while the line with the highest variety of products is responsible for forty-two codes. Bosch Ovar Plant has high flexibility present and it leads to many advantages of this fact, such as:

- Reduce inventory;
- Enables a wider range of business units to negotiate;
- Lower costs to implement other products due to previous experience;
- High adaptation to change when needed
- Short lead times;
- Enable simplification of processes achieved over time;
- Leads to changes of the organization in order to achieve a flexible manufacturing system.

All these aspects contribute to increase productivity, within a flexible manufacturing system and in order to maximize profit.

As for this project, and in order to analyze each work cell, the high runners (products with the highest production) were selected. Table 2 data was collected taken into account the following aspects:

- Observation of the work cell (mainly production complexity);
- Bosch Ovar Plant production forecast for the next three months;
- Products balancing and PQI’s.

Complexity presented in the Table 2 takes into account the study of processes in line, the degree of specialization they require, standard processes and in a small fraction, the cycle time of a product. For example, some products require welding with high precision, and this can only be done by employees with specific training.

At the Bosch Ovar Plant, encasing of the products include specific processes. After observation of the documents previously mentioned regarding each the high-runners of company, it is possible to state:

- 62% of the work cells involve manual screwing for the product assembly;
- 46% of the work cells require the application of gap filler/ thermal paste, using special tools (like a syringe, presented in Figure 21;
- 46% of all work cells in the Plant demand welding.

The analysis of the mentioned processes is presented in section 4.2.

Table 2- Characterization of work cells

Work cell	Family of products	Production Volume	Complexity	Cycle time (s) *
L02B	Video	3	3	2
L03	TT	3	3	1
L06A	Video	3	4	2
L07A	COMM	2	2	1
L08	Video	2	4	2
L09A	Extreme Video	1	3	2
L11A	THT	1	4	3
L13	COMM	2	5	4
L14A	Fire	3	2	1
L16A	THT	2	4	3
L17	COMM	2	3	2
L18	COMM	2	2	1
L19	Extreme Video	1	5	4
L21	Extreme Video	1	3	2
L22	Extreme Video	2	3	2
L24	Extreme Video	1	5	3
L26	Extreme Video	1	4	2
L27	Video	2	3	2
L28	TT	3	3	1
L29	Video	2	4	2
L30A	Video	1	3	3

Production volume (units)	
1	< 1000
2	> 1000 <2000
3	> 2000
4	>10000
Cycle time (seconds)	
1	<100
2	>100 & <300
3	>300 & <1000
4	>1000

3.9 Store the information (SAP)

Bosch is a multi-national company and it works with a high amount of information. This information needs to be structured, transparent and available for the right people. For that, it is uses an ERP (Enterprise Resource Planning) tool, called SAP (Systems, Applications & Products in Data Processing). The most important factor when trying to understand SAP, is to understand the organization of the system. Every employee/department is allowed certain "Transactions", according to their responsibility within the company, its needs and function.

As stated previously, this project work was done within MOE6 (Manufacturing and Operations Engineering 6), department responsible for operations within the work cell, processes and the times of each process, and the SAP Transactions available, within this department, “Material master”, “Work cell definition” and “Routings” are limited when compared with all the capabilities of SAP.

These tools make it possible to create, modify or just view elements of the database, by using different codes to access the data. When preparing a new product there is a need to establish the work cell in which it will be made. This work cell is associated to machines, jigs and human resources (not only the number of people working, but also their formation, needed in processes like welding). On the other hand, it’s necessary to insert the setup times, for people and machines, the time needed to work on the machines and the time people take to operate. All this information is stored in SAP, and is used to control scheduling, costing, capacity planning, simplifying operation maintenance or scheduling data and available capacity.

Routings is a description of the operations (process steps) in order to product. It also contains details about the work cells, such as resources and tools It´s necessary to introduce the times of each process and the whole process, and those values are calculated using balancing and STAB.

SAP contains the bill of materials (BOM) of each finished product. The bill of materials consists of material costs, material description, quantity and unit of measurement. There are other information that can be checked using the SAP system, from costs to the scheduling of each material. The SAP is permanently updated in order to reflect all changes that products are submitted through the Engineering Change Requests (ECRs).

4 Choosing the correct time measurement system and application

The main objective of this project was studying if it is possible to use a MTM system at the Bosch Ovar Plant, and if possible, in which lines it should be applied. Each system has different limitations, so only after analyzing processes within work cells it is possible to choose the most appropriate method for a specific purpose.

The main variables studied were already presented in Table 2, being:

- Production Volume;
- Complexity of processes;
- Work cell cycle time.

As it was mentioned previously, Bosch Security Systems only uses three systems:

- MTM-1;
- MTM-UAS;
- MTM-MEK.

MTM-1 is mostly used for mass production, usually with low cycle times, raw materials replenishment correctly established and workstations specialized and organized. Single body movements are highly detailed and therefore only when all the processes are well established and employees trained and having experience in the position, can this system be precise.

The system mentioned differs significantly between them, both in complexity and analysis. There are clear differences between systems, especially when it comes to movement complexity and times. For example, while UAS has an average process time of 50 TMU, while MTM-1 has an average of 8 TMU (MTM-Vereinigung 2005).

MTM-MEK- (Method-time measurement: MTM in the individual and small batch production), as the name implies, has a very specific use, mainly in make-to-order products, codes with low production volume. The Bosch Ovar Plant produces make-to-order products, however, due to its low percentage, training of people, diversification of templates used and documentation would not be practical.

The study of processes of the workstations used in this project is based on observation of the operator’s movements and subsequent adaptation to a MTM system. This required a long period of observation in order to coordinate time measurements with the worker´s mandatory movements at the workstation and practice for a correct use of the MTM systems. On the other hand there was the need to extend the initial time measurement phase so that the observer didn´t influence the worker´s performance.

For this project a sample size of 20 times were measured for each process or workstation using a chronometer (following the same methodology used previously). The results were compared to the times obtained using a MTM system. The process is simple after some practice but time consuming, since some workstations have high cycle times.

4.1 Creation of a MTM calculator

After the first analysis of the Bosch Ovar Plant, it was necessary to understand the MTM system, its structure, coding and times. Using the information available at the company, MTM-1 and MTM-UAS manuals, a “MTM-1 calculator” was created using Microsoft Excel, so it would be possible to test MTM easily. This file includes the movement codes associated with the predetermined time, for each of the *therblings*, a total of seventeen movements, and explanation for each section of the movement. It was then possible to build the correct code, with the tool providing its time value.

Then, the code of the movements were placed in a standard table (Table 3), with a general description for example “Reach an eraser, distance 20 cm”. The sum of all movements and times in that table establish the process in the specified workstation.

Table 3- MTM-1 calculator table

Nº	Movement description	Code	Time(TMU)	Time (s)
Total				

The first model created was supposed to be simple to use and had a very specific propose, to test if the use of MTM-1 was plausible (if theoretical times were close to the real time), and above all, accurate. A standard MTM-1 table differentiates the movements for each of the workers hand, factor that wasn’t taken into account in the first stage (Table 4).

Table 4- MTM-1 table

	Left hand					Right hand			
Nº	Description	Q	F	Code	TMU	Code	Q	F	Description

In the table above, “Q” represents quantity and “F” the frequency of movements. There is a clear distention between both hands, the time defined is the longest among these values. In the first test, the use of two hands wasn’t taken into account, and the process selected didn’t demand the use of both hands.

A similar “MTM Calculator” was developed to test the MTM-UAS system, based on the same premise, predefined times associated with a specific movement description.

To test the accuracy of the MTM systems, the following calculation in formula (4.1) was performed.

$$MTM\ accuracy = \frac{|Time\ Chronometed - MTM\ calculated\ time|}{Time\ Chronometed}\ x\ 100 \tag{4.1}$$

A workstation of the thermo-technology work cell (Figure 19) was selected to do the first test and the following operations were performed:

1. Get a PCB from the proper location (at the distance of 1 meter);
2. Clean the PCB;

3. Move and position the PCB in the test;
4. Disengage the PCB from the test;
5. Sign the PCB;
6. Identify the PCB by reading the bar code.
7. Get three pieces of housing from a fixed location (all 1 meter away from the workstation);
8. Position the three pieces of housing in the press;
9. Activate the press;
10. Remove the assembly from the press.

Figure 19- First workstation analyzed

This workstation was chosen to be analyzed for the following reasons:

-It involved a wide range of movements, not just hand/arm motions;

-Included non-coded movements, like reading the bar code or testing PCBA, making it possible to study how this processes could be studied using a MTM system;

-Allowed the testing of Basic Procedures in the MTM-UAS, to be more specific, the cleaning of a surface using a piece of cloth.

The results when using each of the systems are summarized in Table 5. The number of motions needed to characterize the process and the accuracy of the MTM system used, compared to the times obtained using a chronometer.

Table 5- Number of movements using each MTM system

	MTM-1 system		MTM-UAS	
Workstation	Nº of motions	MTM accuracy	Nº of movements	MTM accuracy
1	48	19%	12	13%
2	32	17%	16	4%

There is a big difference between the systems when it comes to the number of movement that need to be coded. Using MTM-1, 40 motions are observed and coded. For example, just to document the second step of the workstation (Clean the PCB), 9 different movements are coded (Table 6).

Table 6- Description of "Clean the PCB" using the MTM-1 system

Mov. Nº	Description	Code	Time (TMU)	Quantity	Time (s)
1	Visual inspection	EF	7,3	1	0,3
2	Reach brush(in the table)	R25C	12,5	1	0,4
3	Grab brush	G1A	2	1	0,1
4	Move brush 20 cm	M10Cm	20	4	2,9
5	Visual inspection	EF	7,3	1	0,3
6	Rotate PCB 180º	T180S	9,4	1	0,3
7	Move brush 20 cm	M10Cm	20	4	2,9
8	Visual inspection	EF	7,3	1	0,3
9	Rotate PCB 180º	T180S	9,4	1	0,3

Using the MTM-UAS calculator, the process is not just simpler, but turned out to me more accurate. The simplification of the system provided better results. "Clean the PCBA" is composed by 2 movements (Table 7- Description of "Clean the PCB" using the MTM-UAS system):

Table 7- Description of "Clean the PCB" using the MTM-UAS system

Description	Code	TMU	Q x F	Time (TMU)	Time (s)
Reach and grab the brush	AE2	55	1	55	2,0
Clean the PCBA	M-RAD	145	1	145	5,2

The process of cleaning the PCBA using MTM-1 is described by 2 arm/hand movements using a piece of cloth, turning the PCBA and doing the same movements on the other side. The code "M-RAD", present in the MTM-UAS, represent "Clean an area of 50x50mm". Time obtained using the MTM-1 resulted in a total of 7, 8 seconds, and using MTM-UAS a total of 7,2 seconds. Even though there is a difference between both processes and with the time measured using the chronometer (an average of 7,4 seconds). MTM-UAS is not only easier to use, but the results in this scenario proved to be more accurate, as it is represented in Figure 20.

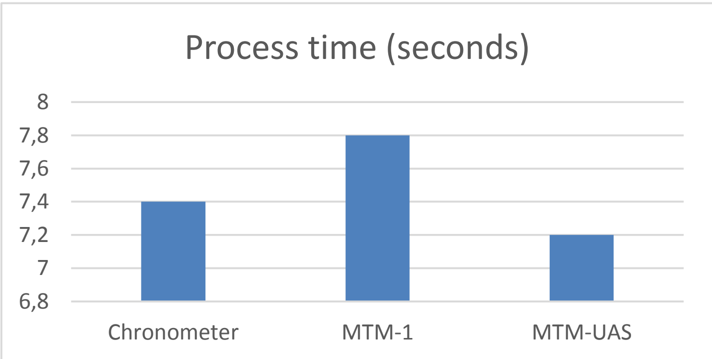


Figure 20- Process time comparison between systems

This difference between times calculated using MTM system and chronometer, and even amongst both systems can be caused by many reasons. One of the prepositions of MTM is that workers are experienced, and more particularly using MTM-1 system, the movements are well established. In this example, the workstation studied is relatively recent, so the process was not yet fully optimized, and while the worker was experienced, the movements aren't mechanized, which affected the operator performance.

Other workstations of the STA-28 were studied in order to test the performance of each system. Like in the one mentioned in the chapter, MTM-UAS proved to be accurate and easier to use.

4.2 Processes and work cells analysis

To facilitate the documentation of the movement in the field and the use of the "MTM calculator", a new table was created for the user to easily identify the three main aspects on a MTM system (Table 8).

In a production line that is already active for some time, the sequence of workstations each worker has to attend tends not to be followed precisely, as documented in the STAB. Mainly because some workstations need more time, and in a work cell with more than just one person, people do other workstations to ease other operators workload. Because of this, the workstations were studied instead of the operators.

Distance depends on the way components are distributed in the line, and the distance from the jigs to the person using them, which demands the visual observation of the line. Tolerance refers to the precision the movements, for example: if it has to be placed in a specific location, or just placed on top of the table.

Table 8- Template Registering line movements

Nº	Description	Nº WorkStation	Distance (cm)	Tolerance

As mentioned in chapter 3.8, work cells L06 and L21 were studied, and with the results of the first work cell tested L28, the tests for this production lines were done using the MTM-UAS system. This selection was based on the following factors:

1. A line with experienced workers;
2. Having relatively high volume demand, approximately 2000 units per month;
3. Many different processes, like welding, screwing;
4. High percentage of manual processes (72%), despite the fact of it having many automatic processes.

The experience mentioned in 1. "A line with experienced workers", is reflected in the time workers take welding or assembling components without clearance. In other work cells, mainly in thermo-technology, the MTM estimated times are below the value of the time measured using a chronometer, so the evaluation of this work cell was useful, reflecting the effects that experienced workers can have on the times of processes of a workstation.

The results of the MTM-UAS analysis are presented in Table 9. There is a clear difference in the values, for many possible reasons, workers performance decay, and possible material miss-positioning or highly mechanized movements.

The study of L06 and L21 allowed the observation of the three main processes performed at the Bosch Ovar Plant:

- Encasing;
- Welding;
- Applying gap filler/thermal paste/glue;
- Testing PCBA's/component assemblies).

Table 9- Comparison between times measured using a chronometer and MTM-UAS system

	Process description	MTM-UAS time (seconds)	Time Measured using a chronometer (seconds)- Average	MTM-Accuracy
Workstation 1	Welding 1	91	90	1,11%
Workstation 2	Welding 2	68	63	7,94%
Workstation 3	Encasing 1	23	20	15,00%
Workstation 4	Encasing 2	34	40	15,00%
Workstation 5	Encasing 3	47	49	4,08%
Workstation 6	Packing	40	39	2,56%
Sum of the values		303	301	0,66%

Encasing

Regular assemblies consisting in assembling components, PCBAs or cables. For these processes, the times obtained when using the MTM-UAS system were accurate. Component or PCBA insertions consist on "Reach and grab", "Position" movements, while the insertion of cables is based on the values of Basic Procedures, in which the type of cables has to be stated.

The workstations characterized as encasing in some cases, also include "Applying gap filler/thermal paste/glue" (which happens in encasing 2, in Table 8), a process analyzed further.

Welding

It was also analyzed what would be the correct way to calculate the welding time. Welding requires high precision movements, which makes the MTM-1 the most appropriate method-time measurement system amongst the systems available.

Welding at Bosch is a process supported by jigs, and these jigs in most cases, not only fix the component in the correct place, but also limit the possible welding locations, preventing many mistakes (Poke-yoke, Figure 5 presents an example of this method). This makes the use of the MTM-1 system possible, if the worker just needs to weld the component established points. However, times obtained using MTM-1 compared to the times measured using a chronometer, weren't satisfactory.

Figure 21- Welding pen in the front, Jig on the background

After analysis, some possible reasons were found to justify the difference in the time calculated and the one measured using a chronometer. The difference can be justified by:

1. Auxiliary movements that have to be done although these are not certain, like the number of times it is necessary to pull the welding wire or to clean the welding pen;
2. Precision of movements required, demanded the worker to be careful, and consequently, perform slower than the standard times;

3. The visual observation necessary for these movements.

Applying gap filler/ glue

Applying gap filler or glue is usually done using a syringe and measuring the amount disposed using a scale (Figure 22). This process can be just classified as precise, if targeted for a very specific location, or just a disposal of a random quantity of paste. When it requires high precision, and many times weighting, it not viable to a method-time measurement system, since it most times it requires visual inspection.

Figure 22- Gap filler syringe with scale

When studying this process, some issues became apparent, like the inconsistent rate of disposed paste by the syringe and times in which the paste dries inside the syringe (disposable units). These problems make the use of predetermined motion time systems a liability, making the use of the chronometer a more appropriate system to measure the time spent.

Testing assemblies/PCBA

Testing the PCBA (example of a testing unit in Figure 23) or assemblies doesn't depend on human actions, so the use of MTM times is not possible. Most of the tests at the Bosch Ovar Plant don't have a defined time, so it is necessary to take samples of the test time, like the ones used in the previous time measurement system.

Then the values are inserted using the code "PTx", with the "x" being a variable, identifying which test it relates to. Time in TMU of the process is easily calculable, using formula (4.2):

$$Time\ TMU = Time\ seconds * 27{,}8 \tag{4.2}$$

Figure 23- Visual inspection test

Process analysis and conclusions

Some of this processes demand very precise work, which includes ocular observation/inspection, thus it is not possible to use neither MTM-1 nor MTM-UAS, since the times obtained won't be so reliable. In some cases, the use of supports/jigs respecting the poke-yoke methodology, like the one it is possible to observe in the background of Figure 21, makes the use of a predetermined motion time system possible, one of the many advantages in its use, however the use of a chronometer is advisable.

MTM-UAS is also more appropriate because if the Basic Processes in this system, like writing. In most workstations, after a component has been tested, it is necessary to sign, to assure that the test was successful. Most work cells have multiple testing workstations, which exacerbates the use of MTM-1 and more complex systems. Since these processes are very frequent, the use of MTM-UAS instead of MTM-1 is significantly more suitable. Other big advantage of MTM-UAS over MTM-1 is the values it has determined for "connecting cables", specifying the type of cable, tolerance of the movement.

The process of observing every movement takes a long time for it to be precise, and even after observation, some details can be overlooked. Since only relying on this information can be risky, the use of PQI's can solve these problems. As mentioned before, the PQI's have to inform the worker of details in the operations, including some aspects of production hard to observe.

When studying this work cells, it became apparent that in order to do a correct evaluation of worker movements, it is necessary to take three different factors into account, as shown in Figure 24.

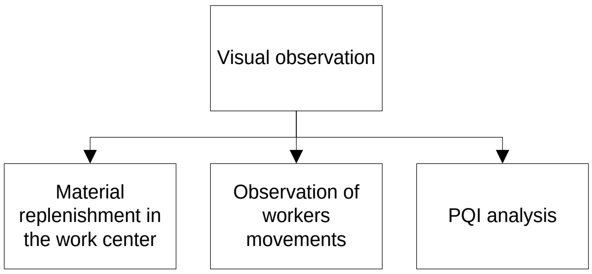


Figure 24- Visual observation guideline

4.3 Choosing the correct measuring system

The choice of the system used, among MTM-1, MTM-UAS and chronometer, in the end, came down to:

- Percentage of manual processes in the work cell and processes' complexity. Percentage of manual processes is simple division of the total time of manual processes by "throughput time". Manual processes include simple movements like encasing or body movements from one workstation to another.
- System accuracy. The distance when using the MTM-1 has to be quantified to the centimeter, while when using the MTM-UAS system, the extension of the movements is only described using a three degree scale (chapter 2.9). Even though replenishment of components is done to specific predefined locations, the extension of movement isn't constant, when using a centimeter scale;
- Simplicity on the application of the system.

According to the study done in lines L21 and L06A, and documented in the chapter 3.8, welding, automatic processes may be complete automatic activities, like testing components/PCBAs (later coded as "PTA"), as well as automatic processes that require human intervention, like welding (coded as "PT").

In work cells that belong to Video and COMM (communication) family of products, the MTM-UAS was considered the best system to be used. All these work cells have automatic and manual processes, like encasing, welding, applying gap filler, in which the standard times of Basic Procedures available in this system were proven to be useful.

L09, L19, L22, L24, L26 belong to the Extreme Video family. In L24 and L26, processes are too complex, and include special testing (for example, soak test). The time of these tests varies from product to product, and even within the same process the standard deviation proved the use of a MTM system to be inaccurate. The low production volume in these work cells also affects the use of a MTM system, since the movements performed by the workers aren't as mechanized as the movements in work cells of Video and COMM families.

The Through Hole Technology (THT) cells, present in Table 2 were analyzed, and the use of a MTM system was not possible, due to very low manual processes (around 17%). Table 10 represents the percentage of manual processes in the lines, and the measurement system to be used.

It was possible to conclude that the use of MTM-UAS system was preferred over the use of MTM-1, based on the reasons specified in the beginning of the chapter. However, in some work cells, the use of a MTM system was not possible, mainly due to processes complexity or mechanization of the movements within the work cells (due to their low production volume and long cycle times).

Table 10- Time measurement system matrix

Work cell	Family of products	% Manual process (time)	MTM-UAS	Chronometer
L02B	Video	79%	X	
L03	TT	57%	X	
L06A	Video	72%	X	
L07A	COMM	59%	X	
L08	Video	68%	X	
L09A	Extreme Video	87%		X
L13	COMM	41%		X
L14A	Fire	64%	X	
L17	COMM	95%	X	
L18	COMM	92%	X	
L19	Extreme Video	81%		X
L21	Video	65%		X
L22	Extreme Video	81%		X
L24	Extreme Video	86%		X
L26	Extreme Video	72%		X
L27	Video	75%	X	
L28	TT	54%	X	
L29	Video	53%	X	
L30A	Video	58%	X	

4.4 Adaptation of the balancing template

A new balancing template was created (ANNEX A), making it possible for the user to plan balancing using both MTM-UAS and the standard template (presented in chapter 3.6) that relied on the measurement of time using a chronometer. In this document, it is possible to estimate the cycle time of the workstation, calculate the costumer takt time, planned cycle time, number of workers and their allocation within the work cell.

First of all, it is necessary to identify to which product the balancing document regards to. A special spreadsheet was created to register not only this, but also:

- The author of the document;
- In which date the document was created, and altered;
- The main components of the product;
- To which family the product belongs to;
- Work cell.

All the factors above are directly related to the MTM system. The author of the document (member of the MOE6 department), component or work cell changes, and most times includes a complete overlook of the production process and consequently, a change in the operators work load balancing.

The second worksheet is a simple table, which is composed only by the data present in table Table 2 and Table 10, providing the information about the work cell, and which system has to be applied.

Since the document is used to two different purposes, the use of MTM-UAS and chronometer, it has to include the means to use both. In order to allow the use of both systems, the template is divided in two systems. The structure is explained better in Figure 25.

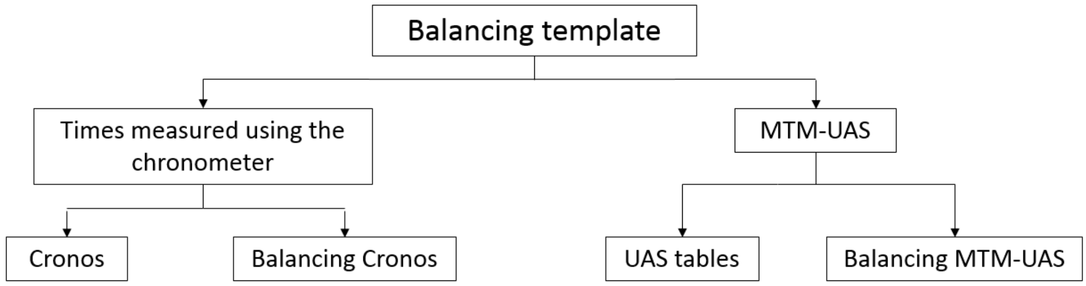


Figure 25- Balancing template structure

The "Cronos" spreadsheet is only used to register the measured time of each process, calculating the sample size, average, standard deviation, minimum and maximum values of the sample. "MTM Tables", as the name implies, includes the MTM-UAS tables, and it's in the document to facilitate its use. These tables have a short description of the movement, codes and specification.

Two different spreadsheets were created to perform the balancing of the work cell, named: "Balancing Cronos" and "Balancing MTM-UAS". The two have a part in common, the total time available in a workday, and with this data, the planned cycle time and takt time. The total available time is dependent in:

- Number of Shifts;
- Planned stoppages;
- Operators performance decay;
- Rest personal care (%).

At Bosch Ovar Plant, the time of shifts is different, the first one is five hours, the second one nine and the third shift nine hours and thirty minutes. In the previous balancing document, it was only possible to calculate the planned cycle time with one shift, however, with the use of checkbox, the calculations become more flexible. Planned stoppages are divided in three sections: food breaks, technical waste and organizational waste (Table 11).

Table 11- Variables for the calculation of the available time

		Planned stopagges(minutes)			
	Shift time(h)	Food breaks	Technical Waste	Organizational Waste	Total time
☐1st Shift	5,0	30			0,5
☐2nd Shift	9,0	30	25		0,9
☐3rd Shift	9,5	30	15		0,8

These sections were obtained with the observation of the Andon system available in the work cells. When using the Andon[3] system, people have to characterize the work cell stoppage, according to the three categories named above and the description. The times used in this table can be standard, a forecast according to other lines or in the case someone is reviewing the process, an update according to past problems. Bosch has an established value to characterize the operators performance decay over time (currently 10%), and this is included to calculate the net production time.

Workers have available a percentage of their time for rest personal care, like for example, eat snacks, drink water or go to the bathroom. This percentage is determined to the whole factory, and the value can change from time to time, based on future company reforms (the percentage of rest personal care can change, depending on the company decision). The costumer takt time and planned cycle time are calculated using the formulas in chapter 3.6.

All tasks and processes timed inside a work cell are registered in the balancing document. The times were measured using a chronometer, are registered using the "Cronos" spreadsheet. When the author is using the MTM-UAS in the work cell balancing, and the process is considered an automatic process, it has to be first registed in the "Cronos" spreadsheet, and then transferred to the "Balancing MTM-UAS" spreadsheet, in the automatic process column (Table 13).

Using the "Balancing Cronos" spreadsheet, the timetable is composed by 8 columns, as it can be verified in Table 12:

Table 12- "Balancing Cronos" template

		Basic time structure					
N	Description	Manual time	Machine run time	Operator work during run time	Cycle time	Needed people	Real people
Total							

[3] Visual system used to notify management, maintenance and other workers of a process problem. At Bosch, the system is activated using a cord above the work cell.

The time of processes, named basic time structure (name previously used), is divided into three different categories, the manual operations (Manual time), like simple assemblies, the machine run time (self-explanatory) and the time the operator uses for other processes while the machines are running (Operator work during run time). This structure is the same as the one that existed before the introduction of MTM.

The part of table on the right (Cycle time, needed people, real people) is used to indicate the work load amongst different workers, and is dependent of the person using the table, since it can be used for the whole work cell or for individual workstations. The cycle time is the maximum amongst the values present in the basic time structure. The formula for needed people is explained on section 3.6, the cycle time of a single process obtained in the same formula. Real people (terminology used in the already existent balancing document) is used to establish the first station an operator is allocated to, most times doing consecutive workstations, since it simplifies organization within the line. The timetable of MTM-UAS is an adaptation of the table above and the MTM calculator (Table 13).

Calculation of manual processes works the same way the MTM calculator, with the codification of the movement, quantity and frequency that the movement is executed and total time.

The automatic processes that require no human interaction have to be coded as "PTA", while automatic processes that require human interaction are coded as "PT".

Table 13- "Balancing MTM-UAS" template

			Manual process				Automatic process	
Nº	WS	Description	Code	TMU	Q x F	Total TMU	Time (s)	Total Time

The main difference between Table 12 and Table 13 is the definition of time on manual processes. When using the chronometer, a simple description can be used to characterize the workload on the workstation, however, it's not possible to do it when using the MTM. Every task performed is registered, and each workstation is characterized by a sum of codes.

"WS" is short for workstation and as the title indicates, is used to identify to which workstation the motion belongs to. The work load of each operator, as previously mentioned, can change, mainly during production planning and be transferred from one to the next workstation. This new column allows a faster allocation of work inside the line. The time of each workstation is then represented using Table 14, a table created to simplify the use of the MTM-UAS system. Needed people represents the same it does on the "Balancing Cronos" spreadsheet.

The cycle time (present in Table 14) is the maximum value between the times of manual or automatic process (coded "PTA"), since these processes can be performed simultaneously to manual processes.

Table 14- Allocation of work amongst workstations

WorkStations			
Nº	Description	Cycle Time(s)	Needed people

Work load distribution amongst operators is the last process when balancing a work cell. First, the number of operators is calculated, using the planned cycle time, and the work cell cycle time. With this value (cycle time) and the number of operators, Table 15 to establish the work load distribution. % unbalanced is the relation between the total time of the operator and the cycle time of the process. Like in the previous balancing template, this value is supposed to be below 10%. The new template follows the same balancing method the company used before the project began.

Table 15- Allocation of workstations among workers

<table>
<tr><td colspan="4">Number of operators</td><td>0</td><td colspan="3"></td></tr>
<tr><td colspan="8">Operators</td></tr>
<tr><td>Nº</td><td colspan="5">WorkStation</td><td>Cycle Time</td><td>% Unbalanced</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

4.5 Simplification of processes

One of the main purposes when using the MTM system is the analysis of movements. This analysis allows its simplification and adaptation in the future.

Like it is referred in the third chapter, a process can be simplified with simple changes. Using the same example of the chapter 2.8, reaching 10 small components and assembling them.

Table 16- Movements description before simplification

Nº	Description	Code	TMU	Q x F	Time (TMU)	Time (s)
1	Reaching and grab component, move close to the assembly	AF2	65	10	650	23,4
2	Position(insert) components	PC1	30	10	300	10,8

Table 17- Movements description after simplification

Nº	Description	Code	TMU	Q x F	Time (TMU)	Time (s)
1	Reaching and grab a handful of components, move the closer to the assembly	AG2	55	1	55	2,0
2	Move from the new location to the assembly	AE1	30	10	300	10,8
3	Insert component, one by one	PC1	30	10	300	10,8

Both movement sequences are represented in the tables above. Grabbing the components one by one, demands more movement precision (grabbing a hand full of components is less demanding/precise than picking one component mixed with others). According to MTM-UAS, this sequence of motions takes 2, 34 seconds, while picking a handful only 2 seconds.

Picking one by one takes in total 34, 6 seconds, while picking by the other method 23, 6 seconds. While this difference doesn't seem very relevant, when it is applied to a complex workstation, it can reduce its process significantly. Just this small change represents a change of 32% in the total time of this process. There are many processes that can be simplified using this system.

This is the kind of processes that can be studied and documented, followed by the correction/optimization of the process by using the MTM-UAS system.

4.6 SAP add-on: CAPP-Knowledge

It was mentioned in chapter 3.9 that times within the work cell were registered using a code for routings. This routing was dependent on the setup times of the work cell, as well as the times of each workstation. CAPP-Knowledge is a SAP add-on used for time management, with a big advantage over the previous routing system.

Using CAPP-Knowledge, all time changes are registered in the system, which provides the user a historical overview over the times of the line. This change may not seem an important aspect, however, transparency is one of Bosch's cornerstones, quality associated with this software.

CAPP-knowledge is a new tool at the Bosch Ovar Plant, so guidelines to use this software was created, to assist the MOE6 department using the new time measurement system. This system allows the insertion of both times measured using a chronometer and the method-time measurement system Bosch Security Systems uses. The guidelines created allowed the reader to understand how to insert the values on the software, and in the future, this data can be used to calculate the same values obtained with the previous tool (routings, section3.9) as control scheduling, costing, capacity planning and available capacity.

Time values on the system is based on three different time elements, named:

- Time study;
- Basic element;
- Analysis.

Time in the time elements is dependent on the type of process being analyzed, since it is divided in three different categories (Figure 27):

- TTB: manual time of the operation. Operations like welding or applying gap filler/silicone are mostly manual, so these are meant to be registered as "TTB";
- TTU: processes time. This category is related to automatic operations, processes not altered by the operator working on it;
- TW: waiting time. Some processes require the operator to work for it to end, for example tests.

Each one of the times elements is associated to a code, to identify the factory, work cell(named group in the software, same value as the one used in data center and in routings), the number and type of operation. All this values have a specific character length. This code can be inserted directly in the bar shown in Figure 26.

The type of the operation has been established previously by the Bosch Security Systems organization. The type of the operation changes between time elements is it related to. Like in the previous system (routings), data can be created, changed or just visualized (Glasses, pencil and paper symbols on the top left corner of Figure 26).

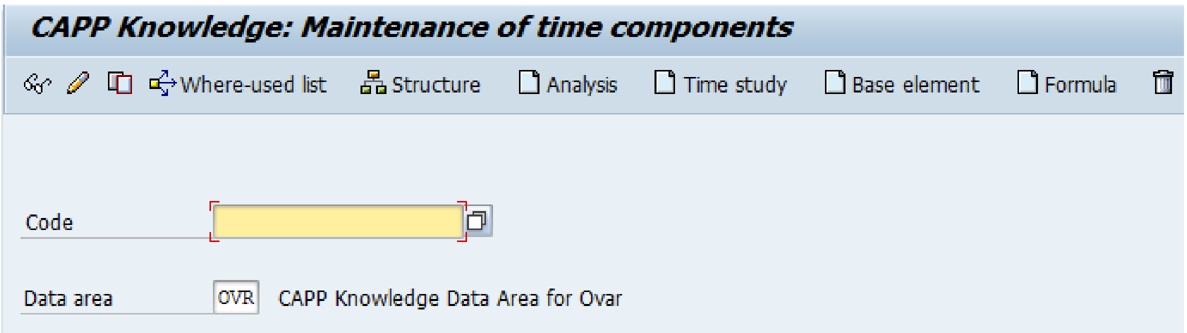


Figure 26- CAPP-Knowledge menu

Time study

Times studies are used for time elements that aren't calculated with the use of an MTM system. Like it was mentioned on chapter 4.3, some processes still have to measure using a chronometer, and this tool takes into account the number of work sequences in these processes and the number of cycles (samples) of times measured.

Basic element

Basic elements (Figure 27) have a similar characteristic to time studies, the basic units in CAPP-Knowledge. While time studies relate to specific events, basic elements are related to time elements used frequently. Basic element codes don't follow the code structure mentioned before, being composed only by the name already predetermined for it.

For example, the system supports the use of MTM-UAS, however the Basic Procedures are not registered in the system, being necessary their input.

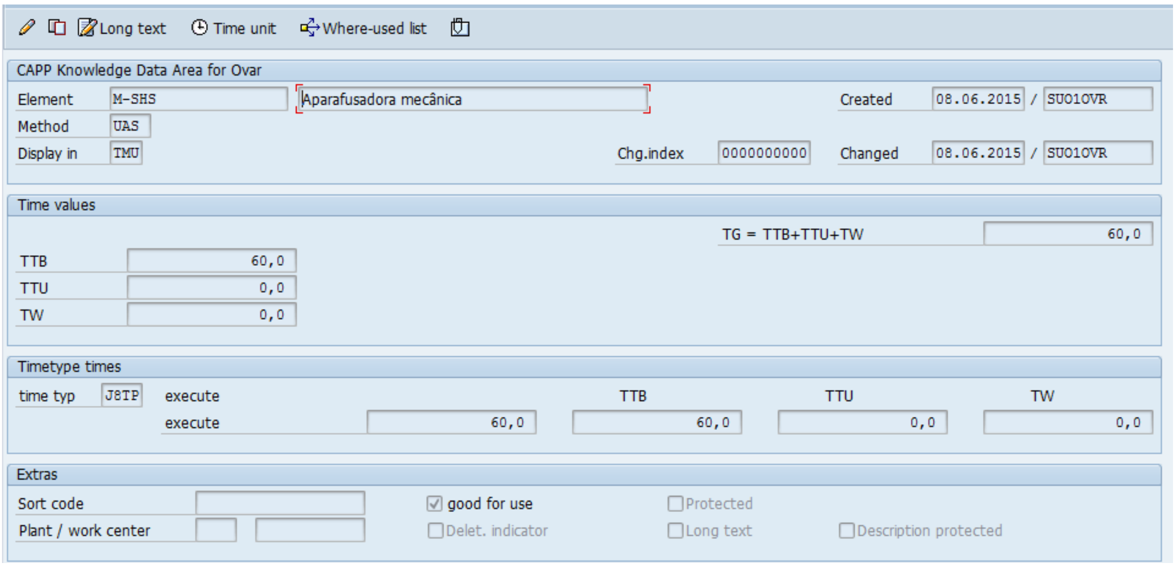


Figure 27- CAPP-Knowledge, Basic element screenshot

Analysis

When registering data into an analysis, it necessary to identify the number of parts manufactured simultaneously, and a set of codes (can be basic elements, time studies or even other analysis), with the associated type. Each of this codes have a time associated to it, but the input of quantity, frequency is necessary. It is also possible to make a distinction between value adding or non-value adding.

Analysis input structure

There is a predefined structure to follow when doing the analysis of an entire work cell. There is a clear distinction between the time person spends working on the work cell, and the setup time. Bosch uses two terms to characterize this factor: VT and TR:

- VT, time person, manual time people take to do all processes inside the work cell, V analysis;
- TR, setup person, time on the setup on the work cell, T analysis.

There is a need to do a characterization of each workstation, both operational time, and the setup time. Then, the sum of all times results in the analysis of the time of the work cell, system represented in Figure 28. Each one of this analysis have a code type associated with it, explained as:

- S analysis, sum of time of every process in a single workstation (VT values);
- V analysis, sum of time of every process in a single workstation (VT values);
- C analysis, sum of the setup time in a single workstation(TR values);
- R analysis, sum of the setup time in a work cell(TR values);
- T analysis, sum of the total time of the work cell.

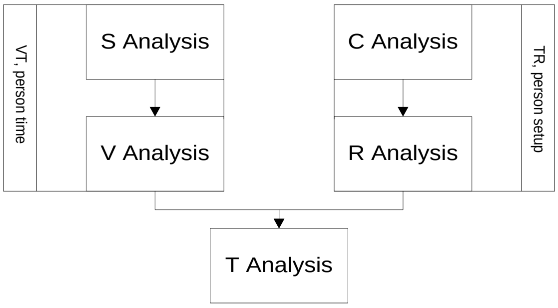


Figure 28- CAPP- Knowledge analysis structure

The values obtained in the T analysis represent throughout time of a product, taking into account the setup time of the line and process in each workstation.

5 Conclusions

At the start of the Project, the use of a method-time system seemed implausible/ inaccurate based on the simplicity of information presented. This information explained a system in which timing of human movements was standardized and applicable in a vast array of processes. However, according to the study of various work cells, with very distinct processes, the use of this system was not only accurate, but it can be time-saving process, in comparison to the use of chronometer.

During the project, a lot of time was spent in the measurement of time of ever-changing processes, an activity that was mandatory, not only to test the veracity of MTM results, but also to test how simple or complex process changes can alter its time. This activity may seem elementary, but in order to have rigorous results, it is necessary to have caution when choosing the work cells, operations and operators analyzed.

When planning a new product, there are several steps to be followed in order to establish an optimized work cell. However, components in the product or the processes used to assemble it can change, to simplify the work. An example of this simplification is the creation of Jigs, that in the end facilitate the process, and adds precision to the movements (due to the jig specific location, and prevention of eventual mistakes in the component positioning). It is also important to take into account the composition of the work cell or the replenishment of material to the workstation. The constant need to change codes can make the time obtained using a MTM system less accurate, and take a considerable amount of time. However, Bosch has a defined methodology when planning the production of a new product, which supports the use of a MTM system.

There are few process that production of assembly lines in the Bosch Ovar Plant has to undergo, which facilitated the analysis of the system. Times for the processes were measured using a chronometer, and compared to the values obtained when using the MTM system. The values obtained in some processes differed greatly from the ones calculated using the MTM systems and reasons for this to happen were studied.

During this analysis, the use of MTM-UAS seemed to be far superior to the use of MTM-1. The time of its Basic Procedures, like connecting electronic cables, proved to be accurate, a clear advantage over the use of MTM-1, since this simplifies the worker analysis. MTM-UAS is also far simpler to use than MTM-1, in which every human movement has to be registered, a time consuming activity, compared to the MTM-UAS system.

Since the times obtained using an MTM system were accurate, this method provides a clear solution to a big problem, the uncertainty of production time in an industrialization project or production changes of processes previously established.

5.1 Future projects

The MTM system is applicable in other areas of production, for example POUPs. During the time at Bosch, a simple template was created, in order to estimate the time of POUP routes, which is divided into two parts:

- Body movements, around the work cells (in order to collect, empty boxes and Kanban), or to other sections of the plant (THT, Clean room, SMT or supermarkets around the work cell);
- Reach and grab, when the POUP has to pick/collect a box of components, and register this action using a bar code system.

The times obtained using this system were satisfactory, however the system wasn't analyzed and tested enough to be considered complete. The POUP times can be explored in future works.

References

Amer, Management. 1957. "INDUSTRIAL-ENGINEERING HANDBOOK - MAYNARD,HB." *Personnel* no. 33 (5):506-506.

Bosch, GmbH Robert. 2015. "Bosch: corporate presentation."93.

Bosch, GmgH Robert. 2008. "Bosch Production System: Basic Training."

Cakmakci, Mehmet, and MahmutKemal Karasu. 2007. "Set-up time reduction process and integrated predetermined time system MTM-UAS: A study of application in a large size company of automobile industry." *The International Journal of Advanced Manufacturing Technology* no. 33 (3-4):334-344. http://dx.doi.org/10.1007/s00170-006-0466-x.

de Bucourt, Maximilian, Reinhard Busse, Felix Güttler, Christian Wintzer, Federico Collettini, Christian Kloeters, Bernd Hamm, and Ulf K Teichgräber. 2011. "Lean manufacturing and Toyota Production System terminology applied to the procurement of vascular stents in interventional radiology." *Insights into imaging* no. 2 (4):415-423.

Directorate, IMD International. 2015. "Historical Development from MTM-1 to the Framework of MTM Building Block systems". Accessed.

Henriksen, E.K. 1973. *Jig and Fixture Design Manual*: Industrial Press.

Lesperance, Jean Paul. 1953. *Economics and techniques of motion and time study*: WC Brown Company.

Morrow, R.L. 1946. *Time Study and Motion Economy: With Procedures for Methods Improvement*: The Ronald Press Company.

MTM-Vereinigung, e. V. Deutsche. 2005. *MTM-UAS Manual de formação*. Edited by Margarida C. Pereira.

Ploix, Stéphane, and Patrick Chazot. 2006. "Iterative expert driven fault diagnosis based on structural modeling". Paper presented at IFAC Symposium SAFEPROCESS.

Saint-Exupéry, Antoine de. 1939. "Terres des Hommes."

Titu, Mihail Aurel, Constantin Oprean, and Daniel Grecu. 2010. "Applying the Kaizen Method and the 5S Technique in the Activity of Post-Sale Services in the Knowledge-Based Organization." *Hong Kong*.

ANNEX A: New balancing template

Balancing cover

BOSCH	Document number: VC XXX		
	Balancing	Versão:	1
		Data:	20/05/2015
Ovar, Portugal	Product: f		

Document Information

Referrence	Created on	Changed on	Description/ Reason	Author
VC XXX	20/05/2015			

Product Information

10NC's	Description	Family	Workcenter
a		Dinion	STA-L06A
b			
c			
d			
e			
f			

Cronos

BOSCH

Ovar, Portugal

Document number: VC XXX

Balancing

Product: f

Versão: 1

Data: 20/05/2015

Operation time (Seconds)

Nº	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sample size	s	Med	Min
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			
																						0			

Balancing MTM-UAS & Balancing Cronos- available time calculation

Cálculo Available Time

Rest personal Care(%):	5,10%

Operators speed	0,1

10% at 70 instead of 80

		Planned stopagges(minutes)			
	Shift time(h)	Food breaks	Technical Waste	Organizational Waste	Total time
☐ 1st Shift	5,0	30			0,5
☑ 2nd Shift	9,0	30	25		0,9
☐ 3rd Shift	9,5	30	15		0,8

Total	9

Available time		
Seconds	Minutes	Hours
28572	476,2	7,94

Balancing MTM-UAS

BOSCH	Document number: VC XXX		
	Balancing	Versão:	1
		Data:	20/05/2015
Ovar, Portugal	Product: f		

	1	2	3
Shifts :			

Capacity Required:	70	Available time(h)	7,94
Customer Takt time(s):	416	Planned Cycle Time(s):	408

			Processos manuais				Processos auto(s)	
Nº	WS	Descrição	Código	TMU	Q x F	Total TMU	Tempo (s)	Tempo total
	1							
	1							

Balancing MTM-UAS – Workload balancing

BOSCH	Document number: VC XXX		
	Balancing	Versão:	1
		Data:	20/05/2015
Ovar, Portugal	Product: f		

Number of operators	0

Operators								
Nº	Work Station						Time	Needed Op.
Total							0	0,00

Work Stations		
Nº	Description	Cycle time
1		0
Total		0

Balancing Cronos

BOSCH	Document number: VC XXX		
	Balancing	Versão:	1
		Data:	20/05/2015
Ovar, Portugal	Product: f		

	1	2	3
Shifts:			

Capacity Required:	70	Available time(h)	0
Customer Takt time:	0	Planned Cycle Time:	0

		Basic time structure						
Nº	Description	Manual time	Machine run time	Operator work during run time	Cycle time	Needed people	Real people	Available capacity
	Total							

Number of operators	0

Operators								
Nº	Work Station						Time	Needed Op.